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CHOICE OF TECHNOLOGY: A CASE STUDY OF THE JAPANESE COTTON WEAVING INDUSTRY 1902–1938*

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I. *Introduction*

Problems and Approach

A rapid increase in the productivity of labor in the Japanese weaving industry as a whole (cotton, silk, worsted and hemp) for the period 1901–1938 was chiefly attributable to technological progress.[1] A major factor responsible for this technological progress was the transition from hand looms to power looms. The ratio of power looms in this industry increased steadily from about 2% in 1907 to 37%in 1920 and 85% in 1938.[2] The ratio in the cotton weaving industry rose from 57% to 91% between 1922 and 1938.[3] Technological progress also depended on improvements in both hand and power looms. Hand looms were improved by the application of a batten (flying shuttle) apparatus and power looms were improved first by a shift from wooden-iron narrow power looms to all iron narrow power looms, then to broad power looms and finally automatic looms.[4]

To what factors were these transformations in the types of looms attributable? Our view is that the choice of technology can be explored by referring to the profit maximizing behavior of entrepreneurs. The rate of net profit in weaving plants depends on factors such as the production efficiency of looms (output per loom, number of workers required to operate each loom, and amount of fuel needed to drive the engine), capital cost arising from looms, engine, buildings and so forth, and the wage rate. An improvement in the economic performance of looms (production efficiency compared with prices) and a wage rate increase, both of which were a result of industrialization, may account for the mechanization of the weaving industry.

A merit of our study lies in the fact that we consider not only the relative profitability of alternative technologies at a single point in time (static analysis), but also the change in relative profitability through time (dynamic analysis). Comparative studies of the same industry (cotton weaving), which are limited to the countries other than Japan, are all static

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[1] The annual growth rate of gross value added per employee for the period 1901–1938 has been estimated at 11.82%, with 81.6% of the growth attributable to technological progress (shifts in the production function) and the remaining 18.4% to an increase in the capital-labor ratio (the power loom equivalent of the number of looms per employee). For detail, see Minami and Makino (1983a), p. 3.

[2] *Ibid.*, Fig. 1.

[3] *Ibid.*, Table 1.

[4] For the history of the use of looms in Japan, see Ishii (1979).

analysis.[5] A study of the historical changes in the economic efficiency of cotton weaving technologies has never before been attempted.[6] In the next section of this paper, the rate of net profit is estimated for five alternative cotton weaving technologies. That is, the rate of net profit in plants equipped with hand looms with batten apparatus (abbreviated to batten looms hereafter), treadle looms, narrow power looms, broad power looms, and automatic looms is estimated for each of the four years of 1902, 1915, 1926 and 1938. In the third section we compare the profitability of these plants in each year and explore factors causing differences in the profitability. Furthermore, we study changes in the differences over time and reveal factors bringing on these changes. In the last part of this section we estimate the rate of net profit for the factory by three kinds of engines to drive looms; steam engine, petroleum engine and electric motors, in 1910 and 1926. Based on these estimates we will study factors for the transition of power sources. The fourth section is for summary and conclusions.

Description of Available Technologies

Five types of looms were available to the Japanese cotton weaving industry prior to W.W.II.[7]

1. Batten (flying shuttle) loom
2. Treadle loom
3. Narrow power loom (power loom for narrow fabric)
4. Broad power loom (power loom for wide fabric)
5. Automatic loom

It may be appropriate to describe the mechanism of these machines here. The motion of a loom for weaving warp and weft threads into cloth consists of three major parts: (i) Shedding, or raising and lowering the warp threads in a predetermined sequence so as to form two lines between which the weft may be passed. (ii) Picking, or placing lines between the divided warp. (iii) Beating up, or striking each weft thread into its appointed position in the fabric.[8]

Prior to the invention of the flying shuttle by John Kay, a weaver depressed treadles with his foot in a sequence suited to the pattern and the scheme of drawing the warp through healds. The warp thread ascended or descended with healds to form a shed for a shuttle to be passed through. The shuttle was thrown between the divided warp by one hand and caught at the opposite side selvage by another hand. After the invention of the flying shuttle, an operator could set the shuttle in motion by giving a sharp jerk to the cord attached to the picker instead of throwing the shuttle. The flying shuttle increased the speed of weaving, because it freed one hand of the weaver and made it possible to devote the hand

[5] Sen (1960), pp. 102–114; James (1976), pp. 143–149; Pickett and Robson (1977), pp. 203–215; Rhee and Westphal (1977), pp. 205–237; von Tunzelmann (1978), pp. 195–202; Pack (1978), pp. 307–325; Hill (1983), pp. 337–353.

[6] Most of empirical studies on technological choice in other industries have also been confined to static analysis. For example, Bhalla (1964); Bhalla (1965); Bhalla (1975), part II; Forsyth (1977); Stewart (1978), chs. 8–10; Ghatak (1981), pp. 153–167.

[7] Hand looms without batten apparatus, or throw-shuttle looms were excluded from the technological possibilities because they had been almost displaced with batten looms by the late of 1900s. See Sampei (1961), p. 67. Since automatic looms were hardly available until the middle of 1920s, they were excluded from the available technologies in 1902 and 1915.

[8] Encyclopaedia Britanica (1958), p. 461.

exclusively to the manipulation of the beating up motion.[9] In the treadle loom, the three motions mentioned above were operated simultaneously by pressing down the treadles. The power loom had a mechanism similar to the treadle loom; an important improvement of the power loom was an application of mechanical power. Owing to this improvement one weaver could attend several looms. The automatic loom was a kind of power loom that was equipped with devices for stoppage of motions in case of warp breakage and for providing new weft thread automatically.[10]

II. *Summary of Estimating Procedure*[11]

Overview

We define the rate of net profit as;

$$\text{Rate of Net Profit}=\frac{\text{Output Value}-\text{Material Cost}-\text{Production Cost}}{\text{Total Capital Cost}}\times 100$$

The value of all the variables in the equation depends not only on the type of weaving technology that is chosen but also on the type of business organization in which it is employed. Hence, before the rate of net profit can be calculated for any of the technologies discussed above, some assumptions about the type of business organizations in which they are employed are required. Following a discussion of these assumptions we develop estimates for each of the variables in the equation in turn, and present estimates of the rate of net profit for each technology in each year.

Assumptions

Our assumptions about the type of business organization in which each type of loom was employed represent the typical relationships in the period studied (see Table 1). Batten looms and treadle looms were installed in the putting-out system and in 'manufacture' (small-scale factory without mechanical power), respectively. On the other hand, power looms were almost always used in factories: we assume that narrow power looms were used in small-scale independent factories equipped with mechanical power (cotton weavers independent hereafter), and broad power looms were employed both in these factories and in large-scale factories operated by cotton spinning companies (cotton spinning-weaving firms hereafter). Use of automatic looms is assumed to be confined to the cotton spinning-weaving firms.

In the putting-out system pieceworkers worked on yarns given out by clothiers and received wages for weaving from them. In some cases looms were owned by pieceworkers themselves, but in others they were owned by clothiers and hired out on pieceworkers. The former type of ownership system was usually found in Higashi-Mikawa, Iyo and Imabari (cotton weaving) and in Kiryū and Kawamata (silk weaving). The latter system was usually found in Sennan, Akita and Banshū (cotton weaving) and in Nishijin and Fukui (silk

[9] Usher (1929), pp. 249–250.

[10] Ishii (1979), No. 5, p. 16.

[11] This estimation is a revision of the previous one conducted in 1983. Estimating procedure is almost unchanged. See Minami and Makino 1983b for the previous estimation.

TABLE 1. ASSUMPTION FOR THE ESTIMATE OF THE RATE OF NET PROFIT BY TYPE OF LOOM

Type of Loom	Type of Entrepreneur	Management System	Ancillary Machines	Factory Building	Apprentice Housing	Debt	Working Days	Number of labor-shifts	Wage level
Batten Loom	Clothier	Putting-out System	×	×	×	×	Slack Agricultural Season	1	Low
Treadle Loom	Cotton Weaver Independent	'Manufacture' System	○	○	○	○	Full time	1	Middle
Narrow Power Loom	Cotton Weaver Independent	Factory System	○[1)]	○	○	○	Full time	1	Middle
Broad Power Loom	Cotton Weaver Independent	Factory System	○[1)]	○	○	○	Full time	1	Middle
	Cotton Spinning-Weaving Firm	Factory System	○[2)]	○	○	○	Full Time	2	High
Automatic Loom	Cotton Spinning-Weaving Firm	Factory System	○[3)]	○	○	○	Full Time	2	High

Note: ○ and × signify that pertinent items are considered and not considered respectively in the estimate.
1) A 5 hp-petroleum engine is used in 1902 and a 5 hp-electric motor is used in 1915, 1926 and 1938.
2) A 20 hp-steam engine is used in 1902 and 1915, and a 20 hp-electric motor is used in 1926 and 1938.
3) A 20 hp-electric motor is used.

weaving).[12] In this paper we assume that the second type of ownership system in which looms were hired out to pieceworkers by clothiers was dominant in the cotton weaving industry as a whole. This implies that the decision maker choosing the weaving technology was not a pieceworker but a clothier. In both the 'manufacture' and factory system weavers worked as employees, and the decision making was done by entrepreneurs. The type of business organization was also related to the type of fabric produced. Clothiers, 'manufactures' and cotton weavers independent produced narrow fabrics for domestic market, whereas cotton spinning-weaving firms produced wide fabrics for export, before W.W.I.[13] During W.W.I. the export of cotton fabrics increased rapidly and small-scale producers began weaving wide fabrics.[14] As a result, the share of broad power looms owned by cotton spinning-

[12] For Higashi Mikawa: Suzuki (1951), p. 119; For Iyo: Kawasaki (1943), p. 59; For Imabari: Otorii (1943), p. 124; For Kiryū: Kawamoto et al. (1901), p. 225; For Kawamata: Shoji (1953), p. 16; For Sennan: Maekawa and Kuramochi (1960), p. 177; For Akita: Hattori (1955), p. 100; For Banshū: Yunoki (1982), pp. 204–205; For Nishijin: Tanaka and Tsutsui (1901), p. 54; For Fukui: Mikami and Idebuchi (1901), p. 14.

[13] Oyama et al. (1935), p. 189. According to Takamura's estimates cotton spinning-weaving firms produced about 95% of all wide fabrics in 1915. See Takamura (1971), p. 232.

[14] Oyama et al. (1935), p. 189.

weaving firms in the cotton weaving industry as a whole went down from 57% in 1922 to 35% in 1938.[15]

Next, it must be noted that a difference in business organization caused a difference in both equipment other than looms (e.g. ancillary machines and instruments, factory buildings, and apprentice houses), and working conditions (e.g. number of working days or hours, wage rate, and number of labor-shifts per day). The putting-out system did not make use of the machines and instruments for preparatory and finishing processes used in the factory system. The costs of factory buildings and apprentice houses were also saved in the putting-out system because pieceworkers worked in their own houses. These facts imply that the amount of capital required for clothiers was not as large as that required by entrepreneurs in the factory system. Therefore, we assume that clothiers were not indebted, whereas entrepreneurs were forced to take out loans to supply the necessary capital. As for working conditions, the number of working days was much smaller in the putting-out system than in the factory system, because peasants were able to participate in the system only during the slack season of agricultural activities. The system for using two shifts a day was limited to cotton spinning-weaving firms.[16] Furthermore, there was a difference in the level of wage rate; the lowest rate being found in the putting-out system, and the highest in the cotton spinning-weaving firms.

Total Capital Cost per Loom

Total capital cost is a sum of fixed capital and working capital. As is shown in Table 1, fixed capital requirements in the putting-out system were looms only, while the factory system required looms, ancillary machines, factory building and apprentice housing. Total capital cost per loom is shown in Table 2. The relative capital cost of broad power loom to narrow power loom was higher in 1902 and 1915 than in 1926 and 1938, because the former

TABLE 2. TOTAL CAPITAL BY TYPE OF LOOM

(Yen)

Year	1 Shift						2 Shifts	
	Batten Loom (Putting-Out System)	Treadle Loom (Weaver Independent)	Narrow Power Loom (Weaver Independent)	Broad Power Loom (Weaver Independent)	Broad Power Loom (Spinning Weaving Firm)	Automatic Loom (Spinning Weaving Firm)	Broad Power Loom (Spinning Weaving Firm)	Automatic Loom (Spinning Weaving Firm)
1902	516	1,836	2,452	15,859	107,729		117,255	
	(972)	(3,722)	(4,721)	(26,166)	(177,551)		(198,450)	
1915	652	3,131	4,950	20,479	140,539		152,524	
	(929)	(5,095)	(7,230)	(25,872)	(177,198)		(198,816)	
1926	1,426	5,810	8,246	12,296	81,398	150,778	102,837	174,003
	(1,336)	(4,746)	(7,096)	(10,765)	(71,273)	(138,136)	(90,530)	(158,998)
1938	1,389	6,104	9,905	14,660	96,892	107,827	111,436	125,526
	(1,062)	(4,466)	(7,237)	(10,871)	(71,892)	(79,304)	(85,153)	(95,442)

Notes: Total capital=fixed capital+working capital. Figures in parentheses are in 1934–36 prices.

[15] For number of broad power looms owned by cotton spinning-weaving firms: Fujino et al. (1979), pp. 75–82; For number of total broad power looms: Nōshōmu Shō and Shōkō Shō.

[16] Oyama et al. (1935), p. 205.

was usually imported until the middle of the 1910s.[17]

Output value per loom per day is calculated by the following formula.[18]

$$O=\frac{V\times F\times T\times 60}{De\times L}\times P$$

- O: daily output value per loom (yen)
- V: revolutions per minute of loom
- F: coefficient of operation of loom (ratio of working day loom was actually operating)
- T: daily working hours
- De: density of weft threads of cloth produced (no. of threads per centimeter)
- L: length of cloth per *tan* (centimeter)
- P: unit price of cloth (yen per *tan*)

Among the six variables determining output value per day the most influential one is V, that is, frequency of picking or beating up motion in a minute.[19] The highest frequency by hand was about 40,[20] but this was almost doubled by the invention of the flying shuttle (batten apparatus).[21] Therefore, the average value of V for batten looms was assumed 90 while for the treadle loom was assumed to be 110.[22] More power is required for the beating up motion and a longer time is needed for the motion with the broad power loom than with the narrow power loom, since reeding space of the broad power loom is wider than that of the narrow power loom. So the value of V for the broad power loom was lower than that for the narrow power loom. Because early broad power looms were usually imports with high productivity, the value of V for the broad power loom was higher in 1915 than in 1926. Apart from the number of loom attended by a weaver, the difference of productivity between power looms and automatic looms lies in the value of F, or the coefficient of opertaion. The value of F for automatic looms was higher than that for either narrow or broad power looms, because automatic looms were equipped with the devices that; 1) automatically stopped all motion when breakage of warp thread occurred and, 2) provided new weft thread automatically. The values of V and F are given in Table 3.

The third factor that determines the productivity of a loom is daily working hours (T).

TABLE 3. PRODUCTIVITY OF LOOM BY TYPE

Year	Batten Loom		Treadle Loom		Narrow Power Loom		Broad Power Loom		Automatic Loom	
	V	F	V	F	V	F	V	F	V	F
1902	90	0.80	110	0.80	140	0.85	180	0.85		
1915	90	0.80	110	0.80	160	0.85	185	0.875		
1926	90	0.80	110	0.80	190	0.85	180	0.85	180	0.92
1938	90	0.80	110	0.80	200	0.85	190	0.85	180	0.92

Note: See text for the definition of V and F.

[17] Ishii (1979), No. 4, p. 28.
[18] Uchida et al. (1953), p. 264.
[19] Ishii (1979), No. 2, p. 36.
[20] Murayama (1961), p. 96.
[21] Ishii (1979), No. 2, p. 36.
[22] Calculated from Sampei (1961), p. 366; Hayashi (1961), p. 49.

It is assumed that looms operated for 12 hours a day in the one shift system and for 24 hours in the two shifts system. Due to the reform of the Factory Act (1923), cotton spinning-weaving firms shortened the daily working hours from the late of 1920s.[23] Therefore, it is assumed that there were 11 working hours in each shift in 1938. In order to obtain annual output, it is assumed that there were 28 working days in a month for all business organizations except the putting-out system where weaving was confined to the slack agricultural season. For example, pieceworkers in Ashikaga region were reported to work only 180–190 days annually[24] and production of cotton fabrics in the farming season declined by one-tenth of what it was in the slack season in Saitama prefecture.[25] Therefore, it is assumed that monthly working days in the putting-out system were two-thirds of those in the factory system. The remaining variables affecting output per loom are the density of weft thread of cotton cloth produced (*De*) and length of the cloth per *tan* (*L*). The values of them differ by kind of cloth. Output per loom is calculated assuming that *Chita-Momen* (a typical kind of gray cloth) was produced by the batten loom, the treadle loom and the narrow power loom, and that triple-width shirting was woven by the broad power loom and the automatic loom.

Material Cost

The amount of cotton yarn consumed in the weaving process is calculated by the following formula.[26]

$$Ma = \frac{Da \times 100 \times Wi \times Lw \times 0.121}{Ca \times 768.1} \times Pn$$

$$Me = \frac{De \times 100 \times Lc \times R \times 0.121}{Ce \times 768.1} \times Pn$$

Ma: cost of warp threads consumed (yen)
Me: cost of weft threads consumed (yen)
Da: density of warp threads of cloth produced (no. of threads per centimeter)
Wi: width of the cloth (meter)
Lw: warping length (meter)
Lc: length of the cloth (meter)
R: reeding space of the cloth (meter)
Ca: no. of count of warp threads consumed
Ce: no. of count of weft threads consumed
Pn: unit price of cotton yarns of n's count (yen per *kan*)

The constant 0.121 and 768.1 signifies a conversion factor from 1 pound to *kan* and a hank of cotton yarn (meter per pound), respectively. The fuel cost differs for each type of engine adopted for driving power looms. It is assumed that narrow looms were driven by petroleum engines in 1902 and by electric motors in other years, whereas broad power looms driven by steam engines in 1902 and 1915 and by electric motors in 1926 and 1938. Automatic looms were operated by electric motors.

Gross value added is defined as the difference between value of output and the sum

[23] Hazama (1978), pp. 357–358.
[24] Kawamoto et al. (1901), p. 124.
[25] Kandatsu (1975), pp. 116–117.
[26] Miura (1931), pp. 241–246.

TABLE 4. GROSS VALUE ADDED PER LOOM BY TYPE

(yen per year)

Year	1 Shift						2 Shifts	
	Batten Loom (Putting-Out System)	Treadle Loom (Weaver Independent)	Narrow Power Loom (Weaver Independent)	Broad Power Loom (Weaver Independent)	Broad Power Loom (Spinning Weaving Firm)	Automatic Loom (Spinning Weaving Firm)	Broad Power Loom (Spinning Weaving Firm)	Automatic Loom (Spinning Weaving Firm)
1902	717	1,247	1,333	4,011	28,937		57,875	
	(1,575)	(2,755)	(2,945)	(8,863)	(63,950)		(127,899)	
1915	814	1,426	1,880	4,913	33,301		66,603	
	(1,480)	(2,593)	(3,419)	(8,934)	(60,559)		(121,118)	
1926	1,293	2,281	3,743	5,818	38,788	42,510	77,577	85,020
	(1,164)	(2,053)	(3,370)	(5,237)	(34,916)	(38,266)	(69,832)	(76,533)
1938	757	1,362	2,320	5,065	33,769	32,665	56,602	60,905
	(692)	(1,245)	(2,120)	(4,630)	(30,865)	(29,856)	(51,734)	(55,667)

Notes: Gross value added = output values − cost of cotton yarn consumed − fuel cost.
Figures in parentheses are in 1934–36 prices.

TABLE 5. WAGE COST PER LOOM BY TYPE

(yen per year)

Year	1 Shift						2 Shifts	
	Batten Loom (Putting-Out System	Treadle Loom (Weaver Independent)	Narrow Power Loom (Weaver Independent)	Broad Power Loom (Weaver Independent)	Broad Power Loom (Spinning Weaving Firm)	Automatic Loom (Spinning Weaving Firm)	Broad Power Loom (Spinning Weaving Firm)	Automatic Loom (Spinning Weaving Firm)
1902	653	1,798	615	615	5,187		10,374	
	(1,443)	(3,974)	(1,359)	(1,359)	(11,463)		(22,926)	
1915	835	2,452	792	792	8,062		16,123	
	(1,448)	(4,460)	(1,441)	(1,411)	(14,660)		(29,321)	
1926	2,512	7,432	2,230	2,230	19,868	4,808	39,735	9,616
	(2,261)	(6,690)	(2,007)	(2,077)	(17,884)	(4,328)	(35,769)	(8,656)
1938	2,264	5,445	3,220	2,320	8,224	1,974	16,447	3,947
	(2,003)	(4,977)	(2,120)	(2,120)	(7,516)	(1,804)	(15,033)	(3,608)

Notes: Wage cost = number of workers × monthly wage rate × 12.
Figures in parentheses are in 1934–36 prices.

of the value of the cotton yarn and fuel used in production. Table 4 shows gross value added by type of loom by year.

Production Cost

Wage cost per loom is the product of the wage rate and the number of workers per loom. Three alternative wage rates are assumed (Table 1). More than one worker was required to operate each batten or treadle loom because they were operated manually.[27]

[27] It was assumed that preparatory and finishing processes were separated from weaving in the putting-out system. Therefore, the number of workers per batten loom in that system ought to be one. But in this paper, the number of workers per batten loom is, instead, supposed to be equal to that per treadle loom in 'manufacture' system, because we treat the expenses of the preparatory and finishing processes in the put-ting- ut system as the wage bill to the assistant workers.

TABLE 6. RATE OF NET PROFIT BY TYPE OF LOOM

(percent)

Year	1 Shift						2 Shifts	
	Batten Loom (Putting-Out System)	Treadle Loom (Weaver Independent)	Narrow Power Loom (Weaver Independent)	Broad Power Loom (Weaver Independent)	Broad Power Loom (Spinning Weaving Firm)	Automatic Loom (Spinning Weaving Firm)	Broad Power Loom (Spinning Weaving Firm)	Automatic Loom (Spinning Weaving Firm)
1902	1.2	−45.1	15.0	7.9	8.6		27.9	
	(−0.3)	(−49.2)	(17.3)	(10.6)	(11.5)		(36.4)	
1915	−13.3	−46.6	9.5	9.5	7.0		22.8	
	(−9.3)	(−52.1)	(11.8)	(13.1)	(10.1)		(31.7)	
1926	−97.0	−103.6	5.3	17.6	11.8	13.1	27.2	32.7
	(−93.3)	(−114.1)	(5.5)	(18.1)	(12.1)	(12.9)	(27.8)	(32.2)
1938	−118.2	−79.3	2.6	18.6	17.5	19.6	28.1	37.6
	(−134.9)	(−99.0)	(3.2)	(23.0)	(21.6)	(24.4)	(33.7)	(45.2)

Notes: Rate of net profit=(net profit/total capital)×100.
Net profit=gross value added−wage cost−depreciation cost−interest paid.
Figures in parentheses are in 1934–36 prices.

A single worker could look after several power looms because they were operated mechanically. The automatic loom required even less labor than other power looms did. Table 5 shows that wage cost per automatic loom was the lowest among the five types of looms in spite of the fact that it had the highest wage rate, because it required the least labor per loom.

In addition to wage costs, production costs include payments to compensate for the deterioration of equipment (i.e. depreciation costs) and payments for borrowed capital (i.e. interest payments).

Rate of Net Profit

The rate of net profit is the ratio of net profit to total capital costs (times 100). Net profit is calculated by deducting production costs from gross value added. The rate of net profit per loom is presented in Table 6.

III. *Findings and Analysis*

Profitability of Hand Looms (Batten Loom and Treadle Loom)

The rate of net profit of batten looms used in the putting-out system exceeded the rate earned by treadle looms in 'manufacture' in each year except 1938. But it should be noted that some advantages of the co-operative 'manufacture' system over the putting-out system are neglected in this calculation. First, because in the 'manufacture' system different production processes for the same product were combined in a single workshop the interval between processes would be shortened[28] and consequently the turnover of capital would be more rapid in the 'manufacture' system than in the putting-out system. Second, transportation costs would be less in the 'manufacture' system because distribution of raw ma-

[28] Hattori (1955), pp. 116–117.

terials and collection of finished goods from pieceworkers was unnecessary.[29] Third, in a single workshop it was possible to check embezzlement of raw materials while this would have been difficult in a system where materials were given out to individual pieceworkers by clothiers.[30] Considering these advantages, it will be evident that the rate of net profit on batten looms used in the putting-out system was overestimated and that on treadle looms employed in 'manufacture' was underestimated. The productivity of the treadle loom, however, was not so high that it could not recover the fixed capital cost arising from establishment of a factory. The development of the 'manufacture' system was discouraged by the low productivity of hand looms.[31] The ratio of hand looms owned by 'manufacture' (here defined as factories with 10 and more workers without mechanical power) to total looms was only about 10% from 1905 to 1921.[32]

Profitability of Narrow Power Loom

The net profit rate for the narrow power loom (15.0%) already exceeded that of the batten looms (1.2%) in 1902. But the supply of power looms was limited[33] and they tended to break down easily during the early years of the 1900s.[34] Therefore, the ratio of power looms to total looms, illustrated in Figure 1, was low during this period. The difference in the net profit rate earned by the narrow power loom and the batten loom expanded between 1902 and 1915 so that choosing narrow power looms became more profitable than before. As a result, in regions where; 1) the factory system had developed, 2) products could be easily produced by power looms, and 3) electric power as a cheap power source was available, the ratio of power looms increased rapidly after 1910 (e.g. Chita, Sennan and Enshū in Figure 1).[35]

Two factors, productivity of loom and wage cost per loom, chiefly accounted for the difference in the net profit rate of the narrow power loom and that of hand looms. Table 7 presents gross profit (gross value added minus wage cost) per loom when the value of productivity per loom and the number of workers per loom for narrow power loom are replaced with those for the batten loom and treadle loom. The relative contribution of each factor to the profitability of the narrow power loom is also shown there. The difference in profitability between the narrow power loom and the batten loom was caused by largely the 'labor saving effect'; it was 65%for 1902, 1915 and 73–76% for 1926, 1938. Almost the same

[29] Hattori (1955), p. 120. The commission paid to intermediaries employed by clothiers to distribute materials to pieceworkers and collect goods from them amounted to 10–15% of total weaving cost in Iyo region from the early 1910s to the middle of the 1920s, see Kawasaki (1943), pp. 8, 59, 63.

[30] Hattori (1955), p. 120. This was also the main incentive to bring together weavers into a single workshop in the English woolen industry, see Ashton (1970), p. 88.

[31] Sampei (1961), p. 386. There was an upper limit in the scale of the 'manufacture' system employing throw-shuttle looms and those that exceeded the limit were hired out to pieceworkers in Bisai region in the middle of the 19th century, because costs incurred by enlargement of workshops employing throw-shuttle looms exceeded benefits of cooperative system, see Shiozawa and Kawaura (1957), p. 162.

Even after 1892 when batten apparatus was introduced there, 'manufacture' enterpreneurs hired out more batten looms than those used in their own workshops, see Ishikawa (1977), pp. 31–33. This implies that enlargement of workshops employing hand looms had an upper limit whether they were equipped with batten apparatus or not.

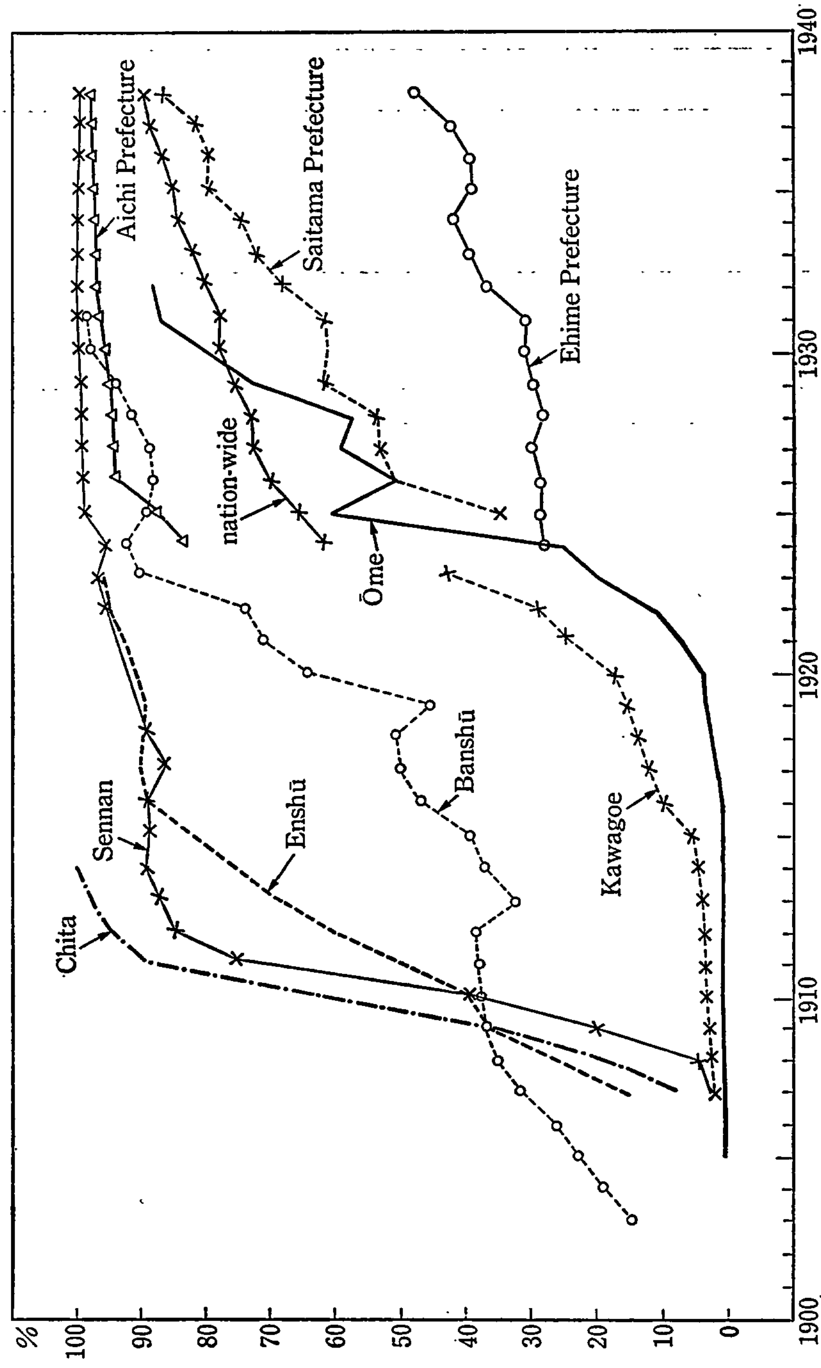
[32] Nōshōmu Shō.

[33] For the supply of power looms see Minami, Ishii and Makino (1982), section III.

[34] Tamura and Asai (1901), p. 41.

[35] Minami and Makino (1983a), sections II and III.

FIGURE 1. RATIO OF POWER LOOMS TO TOTAL LOOMS FOR REPRESENTATIVE REGIONS IN THE COTTON WEAVING INDUSTRY



Source; Makino (1984), p. 32.

TABLE 7. RELATIVE CONTRIBUTIONS OF FACTORS FOR TECHNOLOGICAL PROGRESS

Year	From Batten Loom to Narrow Power Loom					
	Gross Profit for Narrow Power Loom (yen per year)				Relative Contributions (percent)	
	Actual Value (1)	Case 1 (2)	Case 2 (3)	Case 3 (4)	Productivity Effect $\frac{(1)-(3)}{(1)-(2)}\times 100$	Labor Saving Effect $\frac{(1)-(4)}{(1)-(2)}\times 100$
1902	718	−1,110	74	−466	35.2	64.8
1915	1,088	−1,475	185	−572	35.2	64.8
1926	1,514	−6,723	−696	−4,513	26.8	73.2
1938	1,294	−4,535	−116	−3,125	24.2	75.8
Year	From Treadle Loom to Narrow Power Loom					
1902	718	−867	316	−466	25.3	74.7
1915	1,088	−1,196	464	−572	27.3	72.7
1926	1,514	−6,268	−241	−4,513	22.6	77.5
1938	1,294	−4,248	172	−3,125	20.3	79.7

Note: Figures for Case 1 are calculated by replacing the values of revolutions per minute (V), coefficient of operation (F) and number of workers per loom on narrow power loom with those on the batten loom and treadle loom, respectively. Figures for Case 2 are done by replacing V and F on the batten loom and treadle loom, respectively. Figures for Case 3 are done by replacing the value of number of workers per narrow power loom with that per batten loom and treadle loom, respectively.

conclusion can be obtained for a comparison between treadle loom and narrow power loom. Relative comparison between batten and power loom, the 'productivity effect' is smaller in this comparison, because of a higher productivity of treadle loom over batten loom. In both of the two comparisons the labor saving effect increased from 1926 to 1938. This was due to a larger increase in the real wage rate deflated by the price of cotton fabrics.

The quality of cotton fabrics was improved by mechanical weaving.[36] Although this advantage for power looms over hand looms could not be measured quantitatively, it certainly provided an incentive for entrepreneurs to introduce power looms for cotton weaving. Due to these advantages for power looms, cotton weaving entrepreneurs could increase their net profit rate by replacing hand looms with power looms.

Up to now it had been assumed that only batten looms were installed in the putting-out system. But in this system treadle looms were sometimes used and power loom could have been introduced. In order to examine the relationship between the choice of technology and business organization, net profit rate on the batten loom, treadle loom, and narrow power loom are calculated assuming that each loom was introduced into both the putting-out system and the factory system.[37] Table 8 reveals two things: 1) The rate of profit of hand looms (batten and treadle looms) was higher in the putting-out system than in the factory system in 1902 and 1915, whereas in 1926 and 1938 so in the factory system

[36] Fujii (1960), p. 135; Tsukada (1937), p. 33.

[37] We didn't calculate the rate of net profit on the narrow power loom in the putting-out system in 1902 and 1915, because mechanization in the putting-out system was hardly possible until about 1920 when electricity was extensively introduced into rural areas.

TABLE 8. RATE OF NET PROFIT BY TYPE OF LOOM AND BY BUSINESS ORGANIZATION

(percent)

Year	Batten Loom		Treadle Loom		Narrow Power Loom	
	Putting-out System	Factory System	Putting-out System	Factory System	Putting-out System	Factory System
1902	1.2	−64.0	21.6	−45.1		15.0
1915	−13.3	−60.9	6.7	−46.6	−0.5	9.5
1926	−97.0	−70.2	−117.4	−103.6	−19.7	5.3
1938	−118.2	−93.4	−82.7	−79.3	−26.3	2.6

Note: It is assumed that 1 hp-electric motor drives four narrow power looms in the putting-out system.

than in the putting-out system. The profit rate of narrow power looms was, on the other hand, much higher in the factory system than in the putting-out system for all years of 1902–1938. 2) In the putting-out system the hand loom was more profitable than the power loom in 1915, whereas in 1926 and 1938 the narrow power loom was so than the hand loom. In the factory system, on the other hand, narrow power looms were more profitable than hand looms for all years of 1902–1938. This contrast may explain the more rapid diffusion of power looms in the factory system than in the putting-out system. The ratio of power looms to total looms in the putting-out system, which is assumed to include all plants with less than 10 looms, was 5.7%, 10.1%, and 20.6% in 1922, 1926 and 1938, respectively. In contrast, in the factory system, which is assumed to include all plants with 10 or more looms, power looms accounted for 56.0%, 96.1% and 98.6% of all looms in 1922, 1926 and 1938, respectively.[38]

Profitability of Broad Power Loom and Automatic Loom

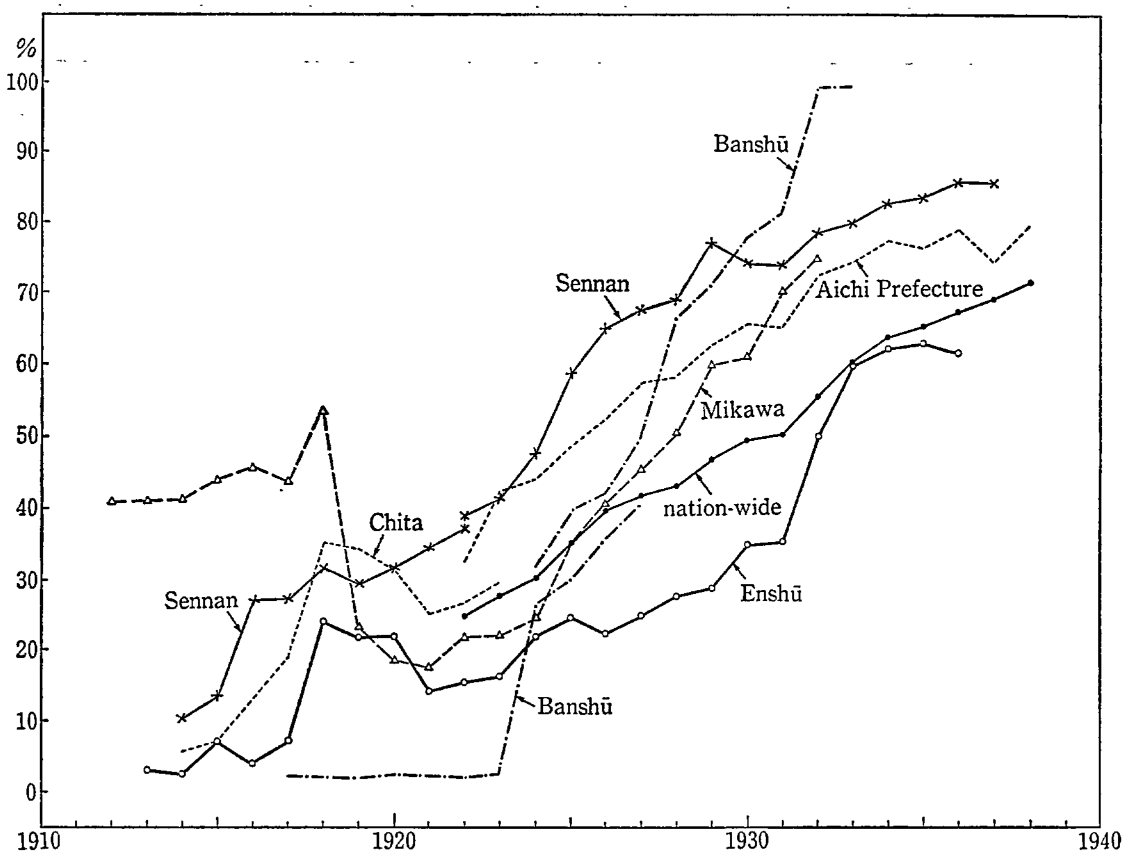
In both 1902 and 1915 the net profit rate on the broad power loom was higher, regardless of its management organization (independent weavers vs. cotton spinning-weaving firms), than that on the narrow loom only when the two shifts system was employed (Table 6). Since only cotton spinning-weaving firms used the two shifts system, choosing the broad power loom was only profitable for them in this period. Or rather, they might have employed the two shifts system so as to compete with small-scale cotton weavers using the narrow power loom. The rate of net profit of the broad power loom in both of the two management organization exceeded that of the narrow power loom in 1926 and 1938 even if the one shift system was used. Hence, it became profitable even for small-scale cotton weavers to introduce broad power looms. This resulted in high rates of diffusion of broad power looms. The ratio of broad power looms to total looms increased rapidly from the late 1910s and exceeded 50% in representative cotton weaving regions (Sennan, Banshū and Aichi Prefecture in the middle of the 1920s, Figure 2).

The first reason why profitability on the broad power loom went up rapidly from the late 1910s was due to a change in the demand structure for cotton fabrics. English cotton fabrics were driven away from Asian market during W.W.I. and Japanese costume became more westernized causing demand for wide fabrics to increase in both foreign and domestic market.[39] This was reflected by price changes for both wide and narrow fabrics. The

[38] For the ratio in 1922, Nōshōmu Shō; For that in 1926 and 1938, Shōkō Shō.

[39] Sampei (1961), pp. 301, 303.

FIGURE 2. RATIO OF BROAD LOOMS TO TOTAL LOOMS FOR REPRESENTATIVE REGIONS IN THE COTTON WEAVING INDUSTRY



Sources: For nation-wide and Aichi Prefecture: For 1922–23: Nōshōmu Shō: For 1924–38: Shōkō Shō. For Enshū: Shizuoka-Ken (1937), p. 29. For Sennan: For 1914–22: Nōshōmu shō Komu Kyoku (1925), p. 102; For 1922–37: Maekawa and Kuramochi (1960), p. 215. For Chita: Yamazaki (1970), pp. 82–83. For Banshū: Kakimoto (1982), pp. 39–45. For Mikawa: Aichi-Ken (1941), pp. 382-383.

per unit price of wide fabrics (triple-width shirting) had been 8 to 9 times that of narrow fabrics (gray cloth) before 1920. In the early 1920s the relative price of wide fabrics increased to 13 or 14 times that of narrow fabrics. This relative advantage of wide fabrics over narrow fabrics persisted until 1938.[40]

A second reason for the increased profitability of broad power looms was that technological progress in the production of looms made it possible to remodel narrow power

[40] Ohkawa et al. (1967), pp. 155–156.

looms into broad power looms easily,[41] and narrow fabrics could be produced simply by cutting off wide fabrics due to advancement in printing techniques.[42] Adopting broad power looms or replacing narrow power looms with broad power looms was facilitated by these technological changes.

Automatic looms had not been widely used prior to W.W.II. The ratio of automatic looms in the cotton weaving industry was only 15% even in 1938 and cotton spinning-weaving firms accounted for about 70% of total automatic looms in the late 1930s. This fact can be explained by the profitability of automatic looms. The rate of net profit of automatic looms was larger than that of power looms, only in the case of two shifts system. Hence, the only firms for which it was profitable to introduce automatic looms in prewar Japan were cotton spinning-weaving firms that employed the two shifts system.

Transition of Power Sources

Table 9 gives the estimates on the rate of net profit by scale of factories (large and small) for 1910 and 1926 under the assumption that power looms were run by three types of engines respectively; steam engine, petroleum engine and electric motor. According to this table, electric motor had the largest profit rate for small- and large-scale factories in both years. A major reason for the relatively great advantage of the electric motor was, as is shown in Table 10, a saving in the costs of capital (depreciation and interest payments) and that in wage payments. The former saving came from a lower price of electric motor than the steam engine and petroleum engines, and the latter was due to a non-existence of special workers to operate those engines (such as boilermen in the case of steam engines). The huge profitability of factories with electric motors gave rise to the rapid electrification in this industry. A proportion of electric power in total power capacity of all engines in the weaving industry as a whole increased from 13.6% in 1909 to 64.8% in 1919, to 81.9% in 1930 and to 91.2% in 1940.[43]

An interesting finding in Table 9 is that the profit rate was almost the same between

TABLE 9. RATE OF NET PROFIT BY FACTORY SCALE AND BY ENGINE TYPE

(percent)

Year	Large Scale[1)]			Small Scale[2)]		
	Steam Engine[3)]	Petroleum Engine[3)]	Electric Motor[3)]	Steam Engine[4)]	Petroleum Engine[5)]	Electric Motor[5)]
1910	16.7	12.0	21.0	6.7	11.3	20.2
	(17.3)	(12.5)	(21.5)	(7.1)	(11.8)	(20.7)
1926	14.1	10.2	17.9	6.7	10.3	17.6
	(14.4)	(10.4)	(18.4)	(6.7)	(10.6)	(18.1)

Notes: Estimates under the assumption of one labor shift. Figures in parentheses are in 1934–36 prices.
1) Factory with 100 power looms (narrow looms in 1910 and broad looms in 1926).
2) Factory with 15 power looms (narrow looms in 1910 and broad looms in 1926).
3) 20 hp.
4) 12 hp.
5) 5 hp.

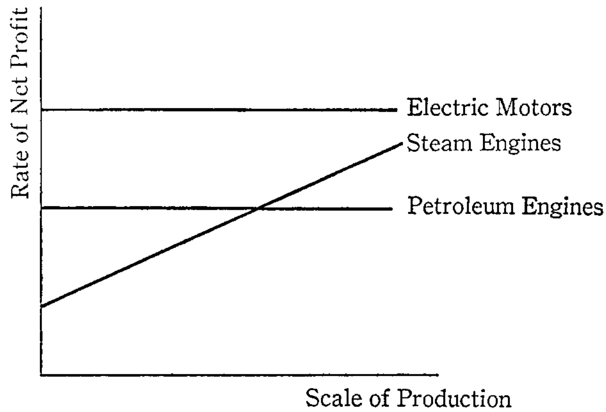
[41] Tanaka (1950), p. 22; Fujii (1960), p. 145; Kobayashi (1981), pp. 209–210.
[42] Sampei (1961), pp. 300–301.
[43] Minami (1987), Table 10–3.

TABLE 10. PRODUCTION COSTS OCCURRING DIRECTLY FROM OPERATION OF ENGINES BY FACTORY SCALE AND BY TYPE OF ENGINES

	1910						1926					
	Large-rcale			Small-scale Factory			Large-scale Factory			Small-scale Factory		
	Steam Engine	Petroleum Engine	Electric Motor	Steam Engine	Petroleum Engine	Electric Motor	Steam Engine	Petroleum Engine	Electric Motor	Steam Engine	Petroleum Engine	Electric Motor
Depreciation for	373	194	100	224	54	25	604	455	85	364	99	22
Engine	(607)	(317)	(163)	(364)	(87)	(41)	(544)	(408)	(77)	(328)	(90)	(20)
Depreciation for	203	203	203	45	45	45	307	307	307	68	68	68
Transmission	(330)	(330)	(330)	(73)	(73)	(73)	(277)	(277)	(277)	(61)	(61)	(61)
Depreciation for	43	12	6	21	6	3	111	32	16	56	16	8
Engine Room	(70)	(20)	(10)	(35)	(10)	(5)	(100)	(29)	(14)	(50)	(14)	(7)
Interest Payment	104	52	37	52	13	9	184	113	57	92	26	13
	(188)	(103)	(79)	(89)	(26)	(18)	(165)	(102)	(51)	(83)	(23)	(12)
Sub-total (A)	723	461	346	342	118	82	1,206	907	465	580	209	111
	(1,195)	(770)	(582)	(561)	(196)	(137)	(1,086)	(816)	(419)	(522)	(188)	(100)
Wage Payment to	544	185	0	185	0	0	2,076	692	0	692	0	0
Workers Who	(902)	(301)	(0)	(301)	(0)	(0)	(1,869)	(623)	(0)	(623)	(0)	(0)
Operate Engine												
Maintenance	108	41	26	27	10	7	228	86	58	57	22	14
Cost for Engine	(176)	(66)	(43)	(44)	(17)	(11)	(205)	(78)	(52)	(51)	(19)	(13)
Fuel Cost	646	3,106	1,128	97	466	169	2,068	7,621	2,732	310	1,143	410
	(1,052)	(5,056)	(1,836)	(158)	(758)	(275)	(1,861)	(6,860)	(2,459)	(279)	(1,029)	(369)
Sub-total (B)	1,308	3,332	1,154	309	476	176	4,372	8,399	2,790	1,059	1,165	424
	(2,130)	(5,423)	(1,879)	(503)	(775)	(286)	(3,935)	(7,561)	(2,511)	(953)	(1,048)	(382)
Total (A+B)	2,031	3,793	1,500	651	594	258	5,578	9,306	3,255	1,639	1,374	535
	(3,325)	(6,193)	(2,461)	(1,064)	(971)	(423)	(5,021)	(8,377)	(2,930)	(1,475)	(1,236)	(482)

Note: See notes of Table 9.

FIGURE 3. RELATION BETWEEN RATE OF NET PROFIT AND SCALE OF PRODUCTION BY TYPE OF ENGINES



the large and small scales in the case of electric motors and petroleum engines, whereas it was so small in the small-scale factory compared to the large-scale factory in the case of steam engines both in the two years. In the large-scale factory the profit rate was the lowest in case of the petroleum engine, whereas in the small-scale factory the rate was the lowest in case of steam engine. Variation in the rate was mainly due to the changes in overhead cost (capital cost and wage payments to workers to run engines). In the case of electric motors and petroleum engines with low overhead cost, rate of profit did not differ among scales of production (Figure 3). In the case of steam engines with large overhead cost, on the other hand, the rate tended to increase with an increase in production scale.[44]

IV. *Summary and Conclusions*

The diffusion of new technology is one of the most important elements of technological progress, which has played a significant role in the process of Japanese economic development. To explore conditions for technological diffusion, therefore, it is indispensable to examine the rapid growth of the Japanese economy. This paper presents an analytical framework for technological diffusion in which entrepreneures realize the profitability of new technology and adopt it into the production process. It is hypothesized that the entrepreneurs choose the technology which has the highest profitability among the alternatives with the result that a certain technology will come into widespread use. In order to ex-

[44] Merits of the electrification in weaving was not limited to savings in cost. The most important among other merits was an improvement of output quality. For instance, in Kawamata, *habutae* produced by hand looms was not of uniform quality even in a single day. This problem sometimes brought complains from customers in France, the United States and other foreign countries. This dissatisfaction, when reported by trading companies to the weavers in various districts, encouraged the introduction of power looms. It was reported that the introduction of electrically driven power looms in Kawamata, completely solved the problem of lack of product uniformity because these motors ran at constnat speed. See Tsunekawa (1916), p. 94.

amine this hypothesis, we study the choice of loom technology in the Japanese cotton weaving industry, one of the leading industries during the prewar period. The rate of net profit among five types of loom technology are estimated for this purpose. We then analyze the relationship between the change in relative profitability of the alternative technologies through time and their diffusion. We also analyze the relationship between the choice of loom technology and business organization.

The results obtained are given as follows:

(i) Generally speaking, at each point in time the loom that had the highest rate of net profit among the alternatives were largely adopted. In 1902 the most profitable loom was the narrow power loom, and the difference in the rate of net profit between the narrow power loom and hand looms widened in 1915, because of the increasing productivity and labor-saving capacity of the narrow power loom. In the 1920s the broad power loom replaced the narrow power loom as the most profitable technology.

(ii) There was a close relationship between the choice of loom technology and business organization. The rate of net profit on modern looms (power and automatic looms) was higher in the modern business organization (the factory system), whereas the rate of net profit on traditional looms (batten and treadle looms) was higher in the traditional business organization (the putting-out system).

Furthermore our study on the rate of profit by engine type (steam engines, petroleum engines and electric motors) has revealed that the electric motor was the most advantageous source of power for weaving. This was responsible for the rapid electrification for the 1910s and 1920s in this industry.

The significances and implications of our study can be summarized as follows. This paper presents the results of one of the few empirical studies of historical change in the choice of technology. The methodology presented here can be used to study technological choice in other industries both in Japan and in other countries and consequently it will be possible to understand the course of technological progress in an industry from an economic point of view. Furthermore, Japan's historical experience in technological choice may provide valuable lessons for countries where future economic development depends upon the choice of technologies appropriate to existing factor endowments. For example, analysis of the choice of looms in the cotton weaving industry where modern technologies and traditional ones long coexisted, may bring a solution to the problem of how to choose the most appropriate technology when modern and traditional technological possibilities exist.

Finally, it is necessary to indicate questions left unanswered and problems involved in this paper. There are two questions. First, although the choice of loom technology are discussed here, we do not consider how the technologies were invented or otherwise made available to the industry. We have inquired into the invention and production of power looms in another paper, where it was emphasized that excellent engineers who had a profound knowledge of both traditional and modern looms, succeeded in inventing cheap power looms appropriate to factor endowments at that time. We found that the looms were provided over a wide area by a number of small-scale loom producers.[45] Second, it is assumed in this paper that entrepreneurs make the choice of technology. However, we do not study as to what kinds of entrepreneurs existed in the prewar Japanese cotton weaving industry,

[45] Minami, Ishii and Makino (1982), section III.

where they emerged from, or how they raised funds for their businesses.[46] Third, the rate of net profit is estimated by using actual figures at that time. But the primary concern of entrepreneurs in choosing a new technology is not current profit but the future profit stream obtained from the investment in the technology. Therefore, it would be more reasonable to assume that the choice of a technology by entrepreneurs depends upon the discount rate that equates the present value of the future revenue stream from the investment with the initial cost of the investment, or internal rate of return. We assume that the rate of net profit estimated here is a proxy for the internal rate of return, but the former is not always identical to the latter.[47]

Although there are a few problems with our approach, it should be applied to technological choice in various industries in order to advance the empirical study of technological progress.

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[46] Weavers' associations (e.g. there were 60 manufacturing associations and 128 trade associations in 1931) played an important role in financing or gathering necessary informations on business. See Minami and Makino (1983a), p. 17.

[47] There have been a few attempts to estimate the present value of a future revenue stream or an internal rate of return. For example, Sansom (1966), Kay (1976), and Stark (1982).

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